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CHOICE AND GROUND FOR DIRECTION OF ENERGY EFFICIENCY INCREASING FOR UKRAINIAN BUILDINGS AND FACILITIES

Проаналізовано наявні організаційні та технічні рішення з підвищення енергетичної ефективності українських будівель і споруд, а також окреслено невирішені проблеми у цій сфері. Відзначено, що складність реалізації технічної процедури модернізації трубопроводів системи центрального водяного опалення перешкоджає підвищенню енергетичної ефективності українських будівель і споруд. Не меншою проблемою є необхідність «грубого» втручання в уже існуючі ремонти, зроблені всередині будівель і споруд.

Ключові слова: *термомодернізація будівель і споруд, фасадна теплоізоляція, модернізація трубопроводів системи центрального водяного опалення.*

1. Introduction

At the present stage of the society development, the most energy-intensive sector in most of the industrialized countries of the world is the systems for ensuring a comfortable life of a person. One of the main tasks is the creation of conditions for the effective operation of life support systems in stationary and in variable operating modes. This approach involves exploring a particular building or structure in a complex and relationship with its environment, that is, to carry out a system analysis.

According to the conclusion of the World Energy Commission «...modern buildings have huge reserves of increasing their thermal efficiency, but the researchers have not sufficiently studied the features of the thermal regime, and the designers have not learned to optimize the heat and mass of the enclosing structures» [1]. It should be noted that the cost (in terms of money) of heating and hot water supply has become a «heavy burden» for the budget of the vast majority of Ukrainian families. The reason is that existing buildings are built without proper attention to saving energy, since when this energy is relatively cheap. Today, its cost is high and its further growth is inevitable.

According to the state building codes (DBN) [2], thermal modernization is a complex of repair and construction works aimed at improving the thermal characteristics of building envelopes, energy consumption indicators of engineering systems and ensuring the energy efficiency of the building at least the minimum requirements for energy efficiency of buildings.

Thus, the essence of the complex thermal modernization (thermal sanation) of a multi-storey or private low-rise building is the development and further application of energy-efficient technical and technological means (methods and devices) that lead to a significant reduction in energy consumption.

A by-side positive result of thermal modernization is the improvement of the thermal engineering parameters of the enclosing structures of buildings and structures. As a result, with an optimistic option, with an inevitable increase in the cost of energy carriers, consumers pay for utility services decreases, and their quality improves. That is, the investigated thermal modernization can be considered as a modern advanced technology both in construction and for public utilities, confirms the relevance of the study. After all, according to the estimates of international experts, in Ukraine, about 300 billion UAH are needed for the insulation of individual houses, and 400 billion UAH for multi-family buildings [3].

2. The object of research and its technological audit

The object of research is the complex thermal modernization of a building or structure, namely its heating system and facade thermal insulation, taking into account foreign experience.

Usually complex thermal modernization is realized by additional warming of the building with mandatory modernization of its heating system [2]. Warming of the house without upgrading the heating system often does not give a positive result for saving energy and often leads even to a negative result – to an increase in energy consumption.

On the one hand, complex thermal modernization requires considerable financial and material costs. But, with full identification of all energy-consuming problems of the building and choosing the correct method for their elimination, complex thermal modernization leads to a total reduction in payment for utilities. And the resulting savings later covers the initial financial costs of complex thermal modernization.

The main reason for the significant heat consumption in the heating of buildings, as indicated above, is excessive heat loss through the outer enclosing structures of the building. The vast majority of existing buildings initially have low thermal insulation of building structures, which leads to significant heat losses through them. Thermal protection requirements (corresponding to them coefficients) in the old building standards (up to 1991), applied to walls, attic floors, etc., were several times lower than modern requirements (corresponding to them coefficients). Therefore, through the construction of old buildings, the heat is lost several times more than in modern buildings.

Another no less important reason for high heat consumption is the low energy efficiency of old heating systems. They were first designed with excessive (several times) heat consumption. Morally and technically obsolete heat points, the hydraulic mismatch of the heat supply system as a result of unauthorized user intervention (independent replacement of radiators, pipelines, etc.), clogged pipelines, there is no thermal insulation in unheated cellars – this is not a complete list of the disadvantages of old heating systems. With such systems, even warming the house, it is impossible to save energy and create comfortable living conditions.

The only way to reduce the material and financial costs of heating today and in the near future is to reduce the amount of consumed heat. This can be achieved by optimizing the system of complex thermal modernization of the building. For example, in numerous cases, poorly insulated external walls in the apartment remain cold.

Especially it is necessary to highlight the need for technical modernization of the heating system, which is due to the following factors. Multi-apartment houses and public buildings are overwhelmingly equipped with central water heating systems – single-pipe, with bottom or top wiring, and with an elevator located in a heating station. Most often these buildings are connected to the heating network. Moreover, the existing heating systems of the old buildings (before 1991) have a number of design flaws, which initially do not allow to save thermal energy and provide thermal comfort in the premises during the entire heating period [2].

For such non-new buildings, the single-pipe heating system was the most suitable, because, and this was important, the pipes needed half as much, which meant that the system cost several times less. However, the single-pipe system had two significant drawbacks: it was impossible to regulate, and it is practically impossible to calculate the amount of heat consumed by one consumer (apartment). And as long as the cost of gigacalorie heat was low (and more often released to consumers significantly below its cost price), there was no need to carry out technical modernization of the existing single-pipe system.

As shown by the research, for the more accurate calculation of the heat consumption and the regulation of the heating system, it is necessary to use a two-pipe heating system [2]. However, with such modernization (transition from one-pipe to two-pipe system of heating) there is a serious problem connected with the violation of existing (made) repairs inside apartments (premises), the vast majority of which at the time of thermal modernization was privatized by residents and received the status of private property.

To a certain extent, the high consumption of heat energy is also due to the lack of its accounting for each consumer (apartment/user), which also does not stimulate the individual economical use of heat. Individual heat consumption accounting, in turn, requires the user to be able to individually regulate the operation of each heating appliance (the use of automatic thermostats on radiators), that is, the ability to influence the reduction of thermal energy consumption.

The heating systems of the old residential heating systems do not function as such. Only a building, properly insulated, and also equipped with automatic temperature controllers of heating devices and means of individual accounting, fully provides maximum effect in the form of reduced energy consumption and utility payments. Partial application of energy-efficient measures, respectively, gives a partial result, and then only if there is a modernized heating system that was able to adequately «respond» to these technical solutions.

Thus, complex thermal modernization involves the development and implementation of innovative technical and technological solutions that reduce energy consumption and, ultimately, «reduce» the size of utility bills. Therefore, the study of such technical solutions that contribute to increasing the energy efficiency of Ukrainian (and not only) buildings and structures is important.

3. The aim and objectives of research

The aim of research is analysis of available technical solutions for increasing the energy efficiency of Ukrainian buildings and structures, taking into account foreign experience.

To achieve this aim, it is necessary to solve the following tasks:

1. To designate unresolved problems in complex technical solutions for thermal modernization of buildings and structures relating to the heating system and facade heat insulation.
2. To substantiate possible ways of solving identified problems that significantly reduce energy consumption.

4. Research of existing solutions of the problem

4.1. Analysis of the directions for carrying out thermal modernization. Solution of problematic issues on thermal modernization of buildings and structures is considered a lot of scientific works. In particular, the fundamental paper [4] explores the various aspects of heat transfer that take place in the implementation of thermal modernization. Analysis of modern power supply systems for industrial enterprises is presented in [5]. Basic solutions for the repair and reconstruction of civil buildings are given in [6]. However, these works do not specify both separate and complex technical solutions for the simultaneous replacement of existing pipelines of the central water heating system and the implementation of the thermal insulation of the facade. Also, effective design parameters of the elements of the thermal modernization system realizing these solutions are not indicated.

The authors of [7] propose a polyoptimal method for determining schemes for thermal modernization of buildings based on the theory of fuzzy sets. As optimization criteria, minimization of the total cost of thermal modernization and maximization of the received energy effect were taken into account.

In [8] it is noted that prefabricated, with bearing walls, apartment buildings represent a significant group of objects, often found in the countries of Central and Eastern Europe. After all, they were built in the 50's, 60's and 70's of the 20th century. Today, the new environmental regulations of the European Union make it necessary to

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modernize such buildings, mainly with regard to energy efficiency. The authors have numerically estimated the frequencies of natural vibrations of buildings before and after thermal modernization, which were confirmed by experimental data obtained for existing structures.

[9] presents test methods and results of estimating the data needed to determine energy consumption in construction, based on measurements in a standard single-family house in Poland. The thermal modernization of the building and its influence on the internal microclimate are rooted in the work [10]. The publication [11] is devoted to the preservation of the historical heritage of buildings subject to thermal modernization. Effective ways to increase the energy intensity and thermal modernization of existing buildings are considered in [12]. An analysis of the options for thermal modernization of a residential house in terms of optimal energy requirements is given in [13]. The study [14] highlights the future problem with the deterioration of the environmental benefits of reducing energy conservation in buildings in district heating systems, as the supply side becomes «more environmentally friendly» and energy efficient.

An analysis of the dynamic behavior of the district heating system was carried out in [15] using the developed mathematical model. The model consists of a simplified district heating system with three end users and a 9 km pipeline network. Also, it is advisable to study the thermal modernization system using structural-parametric models [16], which is part of the integrated approach, and which makes it possible to model the relationships between the structural elements of the investigated system.

4.2. Analysis of patent-protected technical solutions for thermal modernization. A number of technical solutions have been devoted to the problem of thermal modernization of buildings and structures, including patent damages, the main ones of which are described below. So, according to the method of reconstruction of the house heating system [17], this includes the installation of a supply and return risers connected to the heating radiators of individual rooms of the house, while the supply and return risers are installed outside the house wall. After that, the heating radiators are connected to riser pipes with subsequent thermal insulation of the outer surfaces of the pipe elements.

The disadvantage of this method [17] is the lack of optimal geometric parameters and ineffective placement of existing elements of the heat supply system along the front wall, as well as the complexity of realizing the modernization of the pipelines of the central water heating system, in particular, due to the lack of effective procedures for implementing the method.

Also known is the (one-pipe) heat supply system, the pipelines of which are attached to the external wall and covered with a layer of combined thermal insulation, the middle of which is foam, and the last one is a removable panel [18]. The disadvantages of this system is its insufficient efficiency, as well as the need (if there is an appropriate need) of removing the end panel of the thermal insulation layer of the combined thermal insulation after the installation is completed, causes certain difficulties, especially for multi-storey buildings.

Paper [19] describes the structural fastening of combined heat-insulating façade elements to the facade wall with the help of dowels and other fastening elements, which, however, do not provide for optimal placement of heat supply pipelines inside them. Namely, in the insulation, there are pipes in the area remote from the outer facade wall.

In [20], the section of the wall forms lining on the inner walls of the building, fixed with a solution to the wall. This section contains a wall and a plate with holes of equal height and width arranged in parallel. Between them is a layer of heat-insulating material and a coolant pipe. The latter is connected between the supply and return pipes of the central heating system. The disadvantages of this technical solution are the complicated design of the thermal insulation layer and the complexity of its attachment to the front wall.

Another (one-pipe) heat supply system, commonly used in old apartment buildings, contains at least one supply and return pipe risers. The latter are designed to be connected to underground or surface pipelines of central heat supply and permanently connected to these pipelines, as well as apartment heating devices connected to the corresponding risers [21].

The disadvantage of the above-mentioned heat supply system is the need for a complete reconstruction of the building with intervention in existing repairs, previously made inside the premises, as well as the complexity of its implementation.

There is also a heat supply system for a multi-storey house, including the supply and return main collectors of the coolant, at least one pair of supply and return risers connected to main collectors, as well as apartment heaters. At the same time, at least one approaching pair of feed and return risers is installed in each approach section. In any given apartment there are direct and return collectors of inter-apartment wiring, to which all apartment heating devices of this apartment are connected. The apartment registration unit has also been installed, with the help of which the collectors of the apartment building of this apartment are connected to the approaching pair of the supply and return pipes adjacent to this apartment [22].

The disadvantage of the above system is its limited functionality, that is, the impossibility of using the complex thermal modernization of buildings, taking into account the fact that there is no possibility of laying pipelines inside the premises with already completed repairs.

A well-known heat supply system for an apartment building [23], which contains at least one supply and return risers, apartment heaters connected to the respective risers, central heating pipelines, two locking elements intended for connecting the supply and return pipes to the central heating pipelines. This system also contains a controller for automatic control of the heat supply process, two additional locking elements and at least one roof or stand-alone gas heating boiler plant. The power of the latter does not exceed 3 MW. The installation includes a gas boiler, a circulation pump, an expansion tank and a control valve, designed for the controller's controlled gas supply to the boiler. In this case, the output of the gas boiler via one additional locking element is connected to the supply riser. The output of the circulation pump is connected to the inlet of the gas boiler. The input of the circulation pump is connected to the expansion tank and through another additional locking element with a reverse stand. The above-mentioned controller is designed to automatically close some of the locking elements, disconnect the circulation pump and open the shut-off elements intended for connecting the supply and return pipes to the central heating pipelines [23].

The disadvantage of the above-mentioned heat supply system is its insufficient efficiency when performing complex thermal upgrading of the house due to the lack of optimal geometric parameters and the location of the elements of the heat supply system along the front wall.

A method of providing energy for a building with a closed thermoregulation cycle during the heating of a building is known [24], which involves obtaining heat from a low-potential source from which the heat of the circulating heat transfer medium is transferred to the bulk radiator systems of the channels located in the n-layer wall. In addition, it is stipulated that the receipt of heat from a low-potential source is additional, and the main source of heat generation is a high-potential source, installed inside the building. For this, the temperature of the coolant of the volumetric radiator system is regulated by the capacity of the circulation pump, depending on the set temperature inside the building and the fluctuations in the outside air temperatures.

The disadvantage of the known method [24] is its limited functionality.

The most known system and the image of the thermal modernization of a residential building that realizes it are described in the Danfos catalog, which are based both on a single-pipe and two-pipe residential heating system [25]. This system of thermal modernization in the case of a two-pipe system consists of a facade insulation system of the external walls of buildings and structures. The latter is made in the form of a ventilated facade, or one- or multi-layer construction of a heater, or in the form of a «wet» facade. In this case, the facade is made, for example, in the form of slabs or coils. They are attached with polyurethane foams or glue mixtures and dowels to the existing outer wall and covered with a layer of plaster on the reinforcing mesh. The latter is made of high-strength and simultaneously inert material, for example, glass wool.

The heating system for buildings and structures of the thermal modernization system is made as a part of heat sources, for example, in the form of an autonomous boiler house, an individual heat point, a combined heat and power plant or renewable energy sources, a central water heating system. The heaters are connected vertically and in series in the riser through the shut-off and regulating valves. These devices are made in the form of registers of smooth pipes or radiators located in heated rooms and connected to a central water heating system through thermostatic valves. In this case, the vertical central heating system is connected with the top or bottom wiring to a heat source that is connected to a local or central heating network by a dependent or independent scheme.

In turn, during the implementation of the procedures for the above-mentioned method of thermal modernization of a residential house [25], an analysis of the technical state of the thermo-modernized building is carried out on the basis of a set of pre-assembled technical parameters. After that, an energy audit of the thermo-modernized building is carried out, for example, by using a thermal imaging survey. As a result, the places of leaks in the building structure are detected, and as a result, the thermal losses from the heated rooms of the thermo-curved building outside, as well as the temperature of the building structure, are increased, in comparison with the normative indices.

Next, there are design procedures of individual elements and the entire system of complex thermal upgrading of buildings and structures. In doing so, when designing, take into account the design or pre-defined temperature regime for the operation of a thermo-modernized building. This includes the design temperatures used to calculate the load of the central water heating system in the study region, as well as the thermo-technical condition parameter, the material and the wall thickness of the thermo-modernized reconstructed building.

Further, a structural and technological relationship is established between the individual elements of the system and the entire system of complex thermal modernization of buildings and structures as a whole is arranged. After this, the complex thermal modernization of buildings and structures is carried out by installing the parameters and materials of the components of the structural components of the system, which are defined at the previous stage of design, on the existing building of the elements of the complex thermal modernization system.

However, the lack of the above system and the image of the thermal modernization of the residential building that realizes it is their insufficient efficiency in carrying out the complex thermal modernization of the said house due to the lack of optimal composition, optimal geometric parameters and ineffective placement of existing elements of the heat supply system along the front wall. No less important is the geometric parameters of the placement of window openings, the presence of decorative elements and rainwater on the external wall of the facade, as well as the thickness and material of the equivalent facade thermal insulation. These parameters are determined, as a rule, by calculation and experiment in each specific case.

4.3. Aspects of research of facade thermal insulation of buildings and structures. The study of facade thermal insulation of buildings and structures is an important part of the system of thermal modernization, a number of works are devoted. For example, in [26] it is emphasized that there is a need for a global view of the building, in particular, that it is sometimes sufficient to use another insulating material (which allows air to diffuse). The authors of this work note that such approach will help reduce heat loss while maintaining thermal comfort and avoid the disease syndrome for residents.

In work [27] the current state of thermal insulation of walls without expanded polystyrene and existing windows of Alipasino polje buildings in Sarajevo, Bosnia and Herzegovina, where K-5 boiler is operating due to its substation, and current fuel consumption are analyzed. [28] describes a new approach to image-based modeling based on thermographic images, and which is used to study the energy efficiency of building facades. This approach is automated and allows to obtain thermographic 3D-models and ortho-images.

The results of [29] show that the most effective solution for thermal insulation is a ventilated facade in combination with the most shockproof insulation materials, for example, from stone wool and polystyrene. Also the most suitable façade in all climatic zones is an external thermal insulation system in combination with any type of insulation.

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The methodological basis for assessing the importance of the local activity of the external heat-insulating composite system is investigated in [30]. From the point of view of consumers, the use of this facade system provides high thermal stability and can be applied quickly enough with the help of simple operating methods.

In work [31] the expanded use of a double facade in buildings of various types associated with energy consumption and thermal comfort is explored. For this purpose, a simplified mathematical model is developed for dynamic modeling of thermal characteristics, in particular, calculation of thermal energy due to loss of convection from the outer facade layer, solar energy and internal loads. It is noted in [32] that the so-called «green» facades can be a sustainable solution for the construction of new buildings and for the modernization of buildings. This is done to reduce the energy needs of cooling systems, reduce the urban «thermal island» (greenhouse effect) and improve the thermal characteristics of buildings.

[33] considers radiating panels representing energy-efficient sensor heating systems and suitable for low-energy houses. The results of studies on the optimization of heat insulation layers of a house heated using radiant heating systems are described. A new model of a switchable insulating so-called U-element is introduced in [34] consisting of a double-glass block with a translucent insulating panel installed inside. The model is used for parametric analysis, where the influence of various thermo-physical properties on U-values is investigated.

Investigation of the physical and mechanical properties of effective heat-insulating materials from fiber hemp is carried out in [35]. The main components that can be obtained when processing fibrous biomass are hemp fibers and spikes characterized by low density and porous structure. That is, they are suitable for the production of heat-insulating composites. A model for a building with a ventilated facade is studied in [36]. The authors analyze the heat flux of the outer wall, with large temperatures on the outer layer and inside the cavity. The model allows to calculate the energy demand of the building facade, offering and evaluating passive strategies.

Effective intensifying method of manufacturing facade heat-insulating materials from polymer composite materials is low-frequency ultrasonic treatment. The procedure for calculating the structural and technological parameters of an ultrasonic device with a rectangular radiating plate is investigated in [37]. The results of this work should be extended to the manufacture of heat-insulating elements.

4.4. Energy audit and technical and economic aspects of thermal modernization. Technical and economic aspects of thermal modernization of residential buildings are analyzed in [38]. The paper [39] describes the main methods of thermal modernization from the point of view of the authors and the economic efficiency of their implementation, as well as a methodology for their application. The authors made an analysis of existing energy audit methods and identified their shortcomings, as well as a graphical dependence of the change in the thermal resistance of the wall, depending on the type of insulation and thickness. The need for a number of further experiments and a technical and economic analysis of the use of energy systems in general is noted. However, the tandem of technical solutions «replacement of existing pipelines of the central water heating system + implementation of thermal insulation of the facade» and its effectiveness in this work were not considered.

Many works are devoted to the study of various aspects of thermal modernization, carried out, in particular, in Poland. Selected directions for increasing efficiency in supporting the thermal modernization of buildings at the expense of state funding, based on the example of the Republic of Poland, are considered in [40]. In [41], a technical and economic analysis of the work done on thermal modernization in multi-storey houses and communal facilities built in Poland by 1990 is presented. 1441 buildings are analyzed in 7 cities of this country. At the same time, both traditional and industrial technologies (prefabricated multilayered concrete, zeran brick) were used. Energy efficiency and economic analysis of the thermal modernization of forest houses in the National Park of Świętokrzyski are given in [42]. The study of the environmental benefits of investments in thermo-modernization using the example of cooperative housing in the West Pomeranian Voivodeship is explored in the study [43]. The estimation of thermal modernization using the global expenditure method is given in [44]. The problem of managing energy consumption in buildings by modeling and controlling basic electrical appliances is considered in [45]. A simulator is developed that simulates the energy consumption of the load and helps to understand how they contribute to the maximum demand for thermal and electric energy.

In [46], a method for estimating environmental effects for investment is presented, based on the thermal insulation of the exterior walls of the building, taking into account the sensitivity of the selected variables. The assessment methodology takes into account the variables that are the result of the type of the external wall of the building, the sources of heating, the type of used thermal insulation material, and the climatic zone in which the building is located.

5. Methods of research

During the execution of the work general scientific and special research methods were applied:

– economic analysis – in determining the relevance of the research topic;

– statistical analysis – to identify and summarize the trends of changes in the conduct of thermal modernization based on the world experience in its implementation;

– analysis and synthesis of results and retrospective – to study the features, the state of development of thermal modernization of existing buildings and structures in Ukraine;

– historical, evolutionary and logical – for the implementation of theoretical generalizations of scientific approaches to the use of logistic principles for improving the energy efficiency of Ukrainian buildings and structures;

– systems theory and system analysis – to identify strategic prospects for a significant reduction in energy consumption of existing Ukrainian buildings and structures and dissemination of the results obtained to foreign buildings and facilities with similar energy efficiency problems.

6. Research results

The analysis of the above information sources makes it possible to identify a number of unresolved problems in the complex thermal modernization of residential buildings and structures, in particular, its tandem as part of a central water heating system and facade thermal insulation. This, in particular, can be solved by introducing new elements in the form of new transit pipelines of a two-pipe central heating system into the system of complex thermal modernization. No less important task is the optimal placement of new transit pipelines of a two-pipe system of central water heating with reference to the locations of existing heating appliances.

This linkage is carried out depending on many factors, in particular, the thickness of the existing external walls, the geometric parameters of the placement of window openings, the presence of decorative elements and rainwater on the external wall of the facade, from the specified temperature regime of operation, physical and heat engineering parameters, material of execution and thickness of existing external walls of a thermal modernized building. No less important is the optimization of design parameters and the mutual arrangement of new transit pipelines of a two-pipe system of central water heating, the choice of the optimum thickness and effective material of equivalent thermal insulation.

The solution of these tasks on thermal modernization, in particular, will allow:

– to provide an opportunity to take into account and regulate the consumption of heat by consumers, taking into account the operational factors of maintaining the specified temperature regime within the heated premises;
– to increase the coefficient of heat transfer resistance of the existing external wall to the minimum required value, determined in accordance with DBN;
– the possibility of jamming existing pipes of the central water heating system and simple replacement of heating devices in case of such technical need without loss of efficiency of the entire proposed central water heating system;
– to improve the hydraulic regime of the coolant motion and ensure the possibility of using both high- and low-temperature coolant;
– to prevent the freezing of the used coolant even if the engine stops completely during the set time;
– to increase the efficiency of using heat energy in the proposed system of central water heating of premises and to reduce the consumption of thermal energy for maintaining optimal temperature conditions in the living quarters;
– will improve the efficiency of the process of complex thermal upgrading of buildings and structures with the ease of improving the system [47] and the implementation of the method [48], in addition, without actually disturbing the existing repair in the premises located inside buildings and structures;
– to apply the developed innovative solutions in virtually all climatic zones, where there is a need for thermal modernization, especially housing, mainly the period of construction until the 90s of the last century.

It is these directions that form the vectors for the further development of research.

7. SWOT analysis of research results

Strengths. In comparison with analogues, the positive effect of the research object in the form of a thermal modernization system on its internal factors (constituent elements) is the long-term optimization of organizational and technical solutions for improving the energy efficiency of Ukrainian buildings and structures.

Weaknesses. The weaknesses of the proposed complex of organizational and technical solutions for thermal modernization can be attributed to the need for initial capital investments in the system of new transit pipelines for water heating and facade thermal insulation, and also for their installation at the location of buildings and structures. Also, the weaknesses of the proposed organizational and technical solutions can be attributed to their locality with respect to the entire complex system of thermal modernization and the lack of consideration of the interaction of all the constituent elements of the thermal modernization system. After all, the latter also includes translucent structures, automation systems, heat points, combined heat and power plants or renewable energy sources and other elements.

Opportunities. The final result of the practical application of the proposed complex of organizational and technical solutions for improving the energy efficiency of buildings and structures is the receipt of profit in the form of a reduction in the amount of utility payments for heating both for the population and for industrial enterprises. And it is possible without intervention in already made repairs inside the premises. This profit is projected to be obtained in about 2–3 years, depending on the number of thermal modernized objects.

Threats. The enterprise or the operating organization will require initial capital investments in the system of new transit pipelines of water heating and in the facade thermal insulation, and also in their installation at the location of thermal modernized buildings and structures.

The negative impact on the object of research of external factors in the form of the external environment is due to the standard operating life of the facade insulation and the system of new transit pipelines for water heating, which depend on the used materials and the climatic zones for the placement of thermal modernized buildings and structures. However, this period is at least 20 years, which is more than enough for self-sufficiency of thermal modernization. The proposed set of organizational and technical solutions for thermal modernization is protected by patents of Ukraine for the method and device, and a patent-information search has been carried out to confirm their innovativeness.

8. Conclusions

1. The state of the problem is investigated and the available organizational and technical solutions for improving the energy efficiency of buildings and structures are analyzed. It is noted that the main shortcomings of existing technical solutions for the system of thermal modernization are the lack of effective composition, optimal geometric parameters and ineffective placement of existing elements of the heat supply system along the front wall.

Also, the reasons preventing the increase in the energy efficiency of buildings and structures include the difficulty of implementing the technical procedure for upgrading the

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pipelines of the central water heating system. And also the need for «rough» intervention in the existing repairs carried out inside buildings and structures.

2. As an alternative, it is proposed:

– introduction into the system of complex thermal modernization of new elements in the form of new transit pipelines of a two-pipe system of central water heating;

– the mutual arrangement of new transit pipelines with reference to the locations of existing heating appliances.

This linkage must take into account a number of technical factors, among which:

– thickness, physical and thermo-technical parameters of the front wall;

– material of execution of existing external walls of buildings and structures;

– geometric parameters of the placement of window openings;

– presence of decorative elements and rainwater on the external wall of the facade;

– specified temperature operation mode;

– effective material and thickness of equivalent pipe thermal insulation;

– optimum thickness and effective material of equivalent facade thermal insulation.

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ВЫБОР И ОБОСНОВАНИЕ НАПРАВЛЕНИЙ ПОВЫШЕНИЯ ЭНЕРГЕТИЧЕСКОЙ ЭФФЕКТИВНОСТИ УКРАИНСКИХ ЗДАНИЙ И СООРУЖЕНИЙ

Проанализированы имеющиеся организационные и технические решения по повышению энергетической эффективности украинских зданий и сооружений, а также обозначены нерешенные проблемы в этой сфере. Отмечено, что сложность реализации технической процедуры модернизации трубопроводов системы центрального водяного отопления препятствует повышению энергетической эффективности украинских зданий и сооружений. Не меньшей проблемой является необходимость «грубого» вмешательства в уже существующие ремонты, сделанные внутри зданий и сооружений.

Ключевые слова: термомодернизация зданий и сооружений, фасадная теплоизоляция, модернизация трубопроводов системы центрального водяного отопления.

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INCREASING THE ACCURACY OF THE NON-CONTACT TEMPERATURE MEASUREMENT IN THE CASE OF ENERGY AUDITS OF DIFFERENT OBJECTS

Визначено чинники, що впливають на точність проведення енергоаудиту за допомогою тепловізорів. Оцінено ступінь впливу кожного фактору, що впливає на результат вимірювання, та сумарну методичну похибку від одночасної дії усіх впливаючих факторів. Запропоновано способи підвищення точності проведення енергоаудиту, які дозволять зменшити методичну похибку шляхом зменшення ступеня дії впливаючих факторів на точність проведення енергоаудиту.

Ключові слова: *енергоаудит за допомогою тепловізорів, матрічний приймач випромінювання, коефіцієнт випромінювання, точність вимірювання.*

1. Introduction

In conditions of high energy costs, with a large share of energy-consuming buildings, energy conservation is one of the priority tasks for development of the municipal economy in accordance with the Law of Ukraine «On Energy Saving» [1]. Increasing the energy efficiency of buildings and facilities begins with an energy audit that identifies sources of heat loss, shortcomings in thermal insulation, thermal bridges, insufficient insulation density